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THE WEATHERING OF COAL

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The weathering of coal is a subject of perennial interest. Moreover, its importance is not likely to grow less in view of the trend of modern industrial conditions. Almost every circumstance attending the production and use of coal calls for greater flexibility in the current supply. The seasonal changes in temperature, the fluctuating demands for freightage, the periodical disturbances in the labor supply, all argue for the possibility of carrying at certain periods a reserve of fuel to guard against suffering or complete paralysis of industry.

It is not surprising, therefore, to learn of the increasing number of storage plants where coal may be placed in large quantities to supply the needs of great industries which would suffer, if from any cause or combination of circumstances a coal famine should ensue. An example of this is the plant of the Philadelphia and Reading Coal and Iron Company at Abrams, Pennsylvania. At this plant arrangements are made for eight piles of coal each containing 60 000 tons piled on the ground in the open and equipped with modern facilities for dumping and reloading. The storage plant also of the New York Edison Company at Shadyside, New Jersey, where 150 000 tons of coal are stored in three piles on a bed of cinders in the open, and that of the Lehigh Railroad at Wyoming, New York, with a capacity of 100 000 tons, are but a few of the instances where our industries are resorting

to outdoor storage for reserve coal supplies. This method of storing is not only the practice where large quantities of coal are to be taken care of, but there are very few power and heating plants and fuel-using industries that do not find it necessary to pile more or less coal on the ground at least temporarily until room can be made for it in the coal shed or boiler house. The practice in vogue in the coal fields, among coal dealers and all consumers of comparatively small quantities varies greatly. In general, however, it may be said that the coal is either stored in covered iron or wooden bins with slanting bottoms to facilitate its removal, or in ordinary covered bins with earth, cinder or wooden floors from which it is removed with the scoop. In power and heating plants the placing of the coal bins depends upon the position of the boilers and the method used for firing and transportation of the fuel to the building. The United States Navy, which uses about 250 000 tons of coal yearly, has been equipped with large storing facilities, each compartment in the station at the New York Navy Yards having a capacity of 525 gross tons, with floors of portland cement, roof of iron and side walls of portland cement, sand and anthracite cinders. On board vessels coal is stored in whatever room happens to be available.

Aside from these prevalent methods of caring for coal reserves, the practice of storing coal under water is coming into prominence, but the working out of this plan can not be said to have gone further than the experimental stage. The English Admiralty has been experimenting with submerged coal and the Western Electric Company of Chicago has recently built two bins of 4000 and 10 000 tons respectively below the ground level. The plan is to dump the coal into the bins directly from the car and flood it with water until needed for use, when a crane fitted with grab buckets will lift it to the car again.

As one reviews the literature of the subject, it is strikingly evident that well authenticated facts and data are very meagre, with much disagreement among those who have presumed to possess knowledge in the matter. There is a general belief that coal does deteriorate, but under what conditions, to what extent, and according to what principles, are certainly open questions at the present time. The following resumé of the statements by various writers will be of advantage in gaining a present knowledge of the situation. There are included also, references which

deal with the spontaneous ignition of coal, on account of the close relationship of that topic to the one in hand.

Historical Review

After careful experiments, Dr. Richter in 1868[1] concluded that the weathering of coal is due to the absorption of oxygen, a part of which goes to the oxidation of carbon and hydrogen in the coal, and part is taken into the composition of the coal itself; that if the heap becomes warm, either through this process or through any other cause, the action is accelerated, but then falls off and becomes so slow that the changes effected within a year are difficult to estimate; that moisture as such has no direct influence upon the process, apart from the presence of pyrites or from the coal crumbling down more rapidly when wet than when dry, and therefore, more rapidly heating up. At a later date, he concluded that large coal was less affected than small, not because it had less surface, but because small coal was a more active absorbent of oxygen, and therefore, became more rapidly heated; that airways in heaps would have to be very numerous in order to prevent any rise in temperature.

Haedicke in 1880[2], while assigning to pyrites the leading part in spontaneous combustion, agrees that this hypothesis does not hold good unless the temperature is allowed to rise sufficiently.

Professor Fischer of Gottingen as a result of research work prior to 1901[3] concludes that storage depreciation and spontaneous ignition are phenomena of oxidation; the part which is played by iron sulphide has been disputed, but the variances that have given rise to the uncertainty are due to the differences between the different sulphides of iron present in coal. Marcasite for example, he says, is much more weatherable than ordinary pyrites. Actual wetting is much more promotive of oxidation of the iron sulphide than heating in dry or even moist air. He also finds that many coals contain sulphur in the form of unsaturated organic compounds. He finds that those coals which rapidly absorb bromine are those which are most liable to rapid oxidation and spontaneous ignition, and as a practical test he recommends shaking a gram of the finely ground coal with 20 cc. of a half normal solution of bromine for five minutes.

[1]Proc. Ger. Gas Association, 1900.
[2]The Gas World, April 13, 1901.
[3]The Gas World, April 13, 1901.

Then, if the smell of bromine has not disappeared, the coal may safely be put in store; if the odor has gone, the coal should be used up as soon as possible. If the oxygen is absorbed by the unsaturated organic compounds, the coal gains weight, but if absorbed by the carbon and hydrogen, this absorption causes a loss in weight due to the carbon-dioxide and water given off. Whether a coal gains weight is, therefore, dependent upon the composition of the coal. Covering wet slack coal with other coal is apt to produce spontaneous ignition; the danger here appears to arise from the sulphide of iron rather than from the organic compounds. Professor Fischer regards ventilation of the coal heap with suspicion, not because the idea is in itself wrong, but because it is not practicable to ventilate the whole heap sufficiently. He says the coal should be stored dry and kept dry under cover and in layers not too deep.

Durand, 1863[1], explains the spontaneous ignition of coal in the pit by the presence of pyrites, which, becoming heated, gives rise to combustion. Payol maintains that the main cause of spontaneous ignition is the absorption of oxygen accelerated by fine division and heat.

Jackson, 1905[2], says it is well known that coal on exposure to the weather does lose some of its volatile constituents even under ordinary conditions.

In a paper read before the German Gas Association in 1900[3], Herr Sohren said that it is no longer possible for many reasons to operate gas works with a supply of coal renewed from month to month; and that all questions affecting storage have therefore a continuously increasing importance. Undoubtedly there is a greater or less depreciation in quality of coal kept in store; and the causes of this have attracted a great deal of attention, though, on the whole, it is surprising to find to how great an extent the study of the chemistry of coal has been neglected. Questions of this nature first assumed importance in connection with the spontaneous ignition of coal in ships; in 1874 he declares that out of a list of 4485 coal laden ships, no fewer than 60 went on fire.

Lieutenant Commander J. R. Edwards of the United States Navy, 1901[4], said that experience has taught the dealers at Trinity

[1]Journal American Chemical Society, Dec., 1900 and July, 1904.
[2]Engineering and Mining Journal, July 14, 1906.
[3]Gas World, April 13, 1901.
[4]American Society of Naval Engineers, Feb., 1901.

Building, New York, that every time coal is handled there is a depreciation of five per cent in value due to the loss in weight by the breaking up of the coal and the volatilization of the hydrocarbons. It is a fact that the best coal does not disintegrate and powder so quickly as the poorer quality. According to his theory, the hydrocarbons make it less friable.

Groves and Thorp[1] state that gases occluded in the crevices or cavities of coal escape during mining and continue to do so after storing, and that disastrous explosions on vessels carrying coal cargoes have resulted. An analysis of these exuded gases reveals their inflammable nature and suggests the probable action of the air on coal which is exposed to it for any length of time. This latter action is termed "weathering," and consists mainly in the combination of the carbon and hydrogen of the coal with the oxygen of the air, carbonic acid and water resulting. Pyrites, if present, is also oxidized and when present in large quantities causes the coal to disintegrate and oftentimes to be nearly useless. Calorific value is diminished by this exposure to the air and in some cases there is claimed to be 50 per cent loss. Oxidation may proceed so far that elevation in temperature occurs and spontaneous combustion results. Oxidation of pyrites, especially in the presence of moisture, greatly adds to the danger. To avoid the small coal, the packing of coal in lumps in vessels is proposed, but the movement of the ship would break up the coal and only delay the action. Sealing up the coal hermetically has also been suggested, but this would be impossible.

T. Rowan suggests the heating of coal to drive off the moisture before storing on board. The plan is a poor one on account of the cost and the oxidation which the heating would promote.

A. D. Parker, General Auditor, Colorado Southern Railroad, 1902[2], states that the loss in transporting coal has never been definitely determined. It consists of shrinkage, droppings, stealing, etc. Evaporation or shrinkage is inevitable. It is greater with softer coals and diminishes with density. Where coal is placed in storage, shrinkage becomes a very large item.

Mr. Stelkins, in his report before the International Navigation Congress, 1902[3], states that the tendency towards spon-

[1]Chemical Technology Vol. 1, page 82-83.
[2]Railway Engineering News, May 3, 1902.
[3]American Society of Naval Engineers, Feb., 1901.

taneous ignition increases with the height to which coals are heaped. Stacks should not be made higher than five meters. Warm rains during and after stacking and strong compression by dumping coals from a great height all add to the danger of ignition. According to past experiences, gas flaming pit mouth coals ignite most readily, fat pit mouth slack, lean slack and nut less readily, and lump coals only very seldom. When the amount of slack increases, and the amount of stony material increases, the height to which it is safe to store coal decreases. Mr. Zorner in this same convention claimed that lightering coal renders it more liable to physical and chemical attacks and more difficult to use as fuel. Rischowske ascertained a loss of three per cent in calorific power of fresh slack coal after a storage of four months.

Engineering News, July 21, 1904, notes that in the New York Navy Yard space is not an item, but spontaneous combustion is an important one, hence the coal depth is limited to 18 to 25 feet, and the walls surrounding the bins are fire-proof. In each bin which contains 525 tons of coal are placed two four-inch pipes, each containing thermostats electrically connected to an annunciator. These thermostats containing tubes are arranged so as to be moved completely through the coal. A method of removing coal from the bottom of the bins is provided, and this may be done and the portion removed and redistributed over the top to prevent fire.

F. M. Griswold, of the Home Insurance Company, 1904[1] , says that spontaneous ignition is more marked in free burning or so-called "high steaming coals" including "gas coal." These coals usually contain a large per cent of volatile constituents with a modicum of oxygen, and the tendency to ignition is greater when lignite or sulphur in any form, and especially when iron pyrites is present. Dirty or mine-run coals, wherein fine particles sift to the bottom and are compressed are dangerous. He claims that no satisfactory explanation of spontaneous ignition of bituminous coal has been made. The best authorities say it is due to chemical changes in the substance of the coal resulting from the absorptive powers of carbon increasing with the rise of temperature. Rise in temperature may be due to the chemical action in the form of the slow oxidation or to mechanical force or pressure and these conditions may be stimulated by pyrite or

[1]Engineering News 27, 1902, July 21, 1904, Aug. 18, 1904 and Nov. 10, 1904.

moisture. Some claim that over 2½ per cent of sulphur in the form of pyrites is dangerous. Various tests have been proposed to determine the liability of a coal to heat, such as determining the gain in weight of a sample at 250° Fahr. and also by noting the absorption of bromine, but these are not valuable as it is difficult to tell how much oxygen the coal has already absorbed. He recommends that no wood be used in the construction of bins, that all iron work be covered with concrete, that there should be no steam pipes or flues in bins, the coal should not be above a depth of twelve feet, bins should be roofed, permanent pipes should be provided, if possible, containing thermostats through the bin, and when 140 Fahr. is reached something should be done to stop rise in temperature.

Professor Vivian B. Lewis, Royal Naval College, 1906[1], is authority for saying that increase of mass leads to spontaneous combustion. Substances, especially those of vegetable origin, undergo slow oxidation at temperatures below ignition point. A certain increment of temperature is generally needed to start slow combustion, but when once the required rise takes place, the operation commences and the ignition point is reached. Initial increase may be brought about in several ways: first, by physical action as in the absorption of a large volume of gas and its compression within the pores of the substance; second, by a rise in atmospheric temperature; third, by a direct chemical reaction taking place at ordinary temperature and by the action of ferments on moist organic matter. To the first class belongs the spontaneous ignition of a mass of powdered charcoal or lamp black. Coal may be considered as consisting of carbon, hydrocarbons and inorganic constituents. Among the latter is iron pyrites. If piled in heaps and exposed to air and moisture, it rapidly heats and often inflames, owing to the oxidizing action of the air and moisture upon the sulphur; many think this is the cause of spontaneous ignition. Careful study of phenomena occurring during the heating of coal leads to the conviction that pyrites plays but a subsidiary part, and that it is really the absorption of oxygen by the freshly won coal and the activity of the condensed gas in contact with the hydrocarbons of the coal that are the active factors in causing ignition. In the coal seam, coal pores are filled with methane or methane and carbon dioxide.

[1]Engineering and Mining Journal July 14, 1906.

When coal is brought to the surface, it exudes these gases and absorbs oxygen from the air. As long as the pieces are fairly large, no heat is perceptible, but as coal becomes broken up, the surface increases and the absorption of oxygen is increased. Mere absorption of oxygen is insufficient to bring about serious consequences unless there is an initial rise in temperature. Hence, spontaneous ignition is found to occur when cargoes go through the tropics and when coal is stored close to boilers, steam pipes, fire boxes, etc. Water aids the action of the occluded oxygen, and hence rain, when coal is being loaded, causes danger. Ventilation of coal on land may aid in preventing ignition, but this is hard to obtain on shipboard. Steam and water have failed to quench fires successfully. Sulphur dioxide and carbon dioxide will extinguish the fires, but not cool the coal and prevent another fire. He suggests that liquid carbon dioxide be placed in vessels whose nozzles are made of an alloy of lead, tin, bismuth and cadmium melting at 93° C. and that these vessels be placed in the coal bins. When the melting point of the alloy is reached, the carbon dioxide will quench the fire, cool the coal, be absorbed by the coal and prevent any further occlusion of oxygen.

A. E. Dixon, 1906[1], says that bituminous and semi-bituminous coals are losing constantly in heating value. Gas is being liberated, and the loss is greater in a warm climate and in warm weather. Bituminous coals undergo a slacking process, the lumps shrink and the percentage of dust increases. In winter the contained moisture freezes and breaks up lump coal. Spontaneous ignition occurs with bituminous, friable coal, and particularly with those grades containing brasses or iron pyrites, and when the coal is damp, the trouble is augmented. The cause is probably due to the absorption of oxygen by carbonaceous material, just as is the case with oily cotton waste.

H. R. King, 1905[2], claims that the carefully executed tests in Europe show that 30 per cent of the fuel value of coal is lost in six weeks when coal is stored out of doors.

The Naval and Military Record of England[3] gives an instance of where the British ship, Spartiate, required 3000 tons of coal stored in England in running to China and 4400 tons of practical-

[1]Engineering Magazine, Sept., 1906.
[2]Journal Western Society of Eng., Aug. 1906.
[3]Engineer, July 24, 1903.

ly the same grade of coal that had been stored in China for the return trip.

Lord Charles Beresford, 1903[1], stated that in his experience a vessel would have to consume more than twice the normal amount of coal per indicated horse-power, if the coal had been kept too long in store.

Churchyard, locomotive engineer of the Great Western Railway, England, 1902[1], stated that judging from his personal experience and observation, the loss of stacked coal in steam raising power is about 10 per cent.

Mines and Minerals, 1901[2], says that for many years there has been in vogue in New South Wales a custom of taking certain percentages from the gross weight of coal cargoes, giving bills for the net quantity only. The idea was to allow for the wastage which it was thought took place in various ways between the time of weighing at port and delivery. The practice has been to deduct two per cent from the gross weight of foreign exportations and one per cent from that intended for intercolonial markets. On account of the dissatisfaction with this method, on January 1, 1901, the deduction on foreign cargoes was reduced to one per cent and no allowance is now made on intercolonial cargoes.

The Journal of the Society of Chemical Industry, 1894[3], says that various kinds of coal were exposed freely to the air, immersed for twelve months in water both running and stagnant and changes produced in their composition and heat of combustion determined. The three kinds of coal used were, (1) from Frankenholz mine, Bavaria; (2) from Drocourt; (3) from Arsean, Prele. These coals were broken and passed through 10 mm. mesh, but not 3 mm. mesh. Measurements show that exposure to the air or immersion in water for the time indicated produces changes in the composition and heat of combustion which are so small as to be neglected for practical purposes.

John Macaulay, General Manager of the Alexandra Docks and Railway, Newport, Monmouthshire, 1903[1], estimates that in case of coal stacked by the Mersey Railway the loss was between 10 and 12 per cent and, if kept over a year, the greatest loss is in the first twelve months. In hot climates the loss is greater. Mr.

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[1] Practical Engineer, Oct. 2, 1903.
[2] Mines and Minerals, 1901, p. 6.
[3] Jour. Soc. Chem. Ind., 1894, p. 1182.

Macaulay says that the mud men along the Usk River gathered parts of submerged cargoes and found that the coal gave a hotter fire than did fresh coal. In North Pembrokeshire, they refloated a vessel which had been sunken for two years and found that the coal was the best they had ever used. Mr. Macaulay's own experiments include the placing of a sample of the best Monmouthshire coal under sea water for two months and comparing the calorific value before and after immersion. He found the loss in heating value was less than one per cent. In his further experiments he made a practical test of fresh coal and coals known to have been submerged various lengthy periods of time, by using them in a locomotive hauling a known load a certain distance under similar conditions. His first sample was the best Monmouthshire coal procurable, the second sample had been under water three years, the third had been submerged ten years, the fourth had been recovered by mud men outside of the mouth of the River Usk. This latter was driftage from the wrecks in the Bristol Channel, and had probably been under water considerably longer than ten years; this sample he called "river coal." The order of value in steam raising and actual working results, in which the coals came out in the tests, was: (1) the river coal; (2) coal that had been under water ten years; (3) fresh coal; (4) coal that had been under water three years. Comparing values with the fresh or test coal, the river coal was four per cent better, and that which had been under water ten years 1.8 per cent better. That which had been under water three years had lost 1.6 per cent of working power. The high value of the older river coal, he says, may probably be accounted for by the fact that in traveling through the mud and sand that gave it its rounded form, the harder and better kernels, as it were, had been preserved, and the looser textured, less valuable outside portions were worn away. As a result of his experiments Mr. Macaulay concludes that steam coal loses very little of its power by submersion under water for the length of time that it would reasonably be kept in naval store, and that as it is so important to naval vessels to gain the benefit of their full working power, and so much of this is due to the coal, the subaqueous storage of coal is advisable in place of the present methods of storing with access to air, by which so high a percentage of working power is lost.

Summation of Opinions

Judging from these opinions of practical engineers and scientists, the present methods of coal storage without doubt often result in much loss from fires of spontaneous origin and more or less loss by a deterioration in fuel value of the coal itself. The leading factors entering into the cause of these losses have been pointed out as being; (1) the kind of coal as to its volatile combustible content; (2) the presence of occluded inflammable gases in the coal both before and after mining; (3) the presence of pyrites or other sulphur compounds; (4) the size of the coal: (5) the presence of moisture: (6) the temperature; and (7) the accessibility of oxygen to the coal.

From the evidence at hand there seems to be very little doubt that the coals of the lignitic, bituminous and semi-bituminous character with their relatively high amounts of volatile combustible matter have a much greater tendency to weather than the anthracites where the volatile matter is low. There is considerable evidence that methane and other inflammable gases formed during the decomposition of vegetable matter which produces the coal are contained in the crevices of the coal as it lies in the earth, and are liberated both during and after mining. This exudation of inflammable gaseous matter may be a prime element in mine explosions, and its continuance after storage may be a large factor in the deterioration processes.

Opinions differ as to just what part sulphur compounds, the most important of which is pyrites, play in the deterioration of coal. Some assign the leading part in cases of spontaneous ignition to pyrites, while others think that its action in this connection is of only minor importance and that absorbed oxygen has most to do with this phenomenon. Observations on the effect of the air upon pyrites, however, seem to have pretty generally established the notion that pyritic oxidation tends to raise the temperature of the coal as well as to increase the tendency of the coal to break up, and that this oxidizing action is quite appreciably increased by the presence of moisture.

That slack is much more liable to spontaneous ignition and the deteriorating influence of weathering agents seems to be the general opinion. Having more surface the finer particles absorb oxygen much more rapidly and this rapidity of absorption causes an increase in temperature which in turn produces better condi-

tions for absorption and chemical action between the carbon, hydrogen and pyrites of the coal and the absorbed oxygen. It would seem that the finer coal would hold the moisture longer, resulting in a greater use being made of its catalytic qualities.

It is thought by some authorities that the only part moisture plays in the deterioration of coal is to materially assist the pyritic oxidation or by alternate freezing and thawing in the crevices of the coal to expose more surface to weathering agents. There are many, however, who believe that aside from increasing the oxidation of pyrites, water has to do with other chemical activities, which result in the decomposition of the coal. These believe that oxidation of the carbon and hydrogen of the coal is hastened by the action of the water present. This latter view seems to be based on the fact that moisture has seemingly, in some instances, greatly increased the deterioration of practically non-pyritic coal.

That an increase of temperature has much to do with increasing the activity of the other deteriorating agents is the general belief. This rise of temperature whether coming from outside sources or physical or chemical action within the coal tends to accelerate the absorption of oxygen and thereby increases the oxidation going on and also evaporates the gases which may still be occluded in the coal. Thus heat assists in decreasing the fuel value of the coal and at the same time increases its liability to ignition. That the exclusion of oxygen from coal will decrease its loss in heating value is a growing belief.

From the evidence at hand, therefore, it would seem that not only do observers differ widely as to the causes and extent of weathering, but no very exact study of the problem has been made in all of its phases on which could be based very much either of theory or fact concerning the deterioration of coal in storage.

Any discussion of the matter from our own standpoint will be reserved until after presenting the results of our experiments as outlined in the following pages.

Experimental Work

It seems necessary to concede at the outset that coals will differ as to the extent of their deterioration, because of their individual peculiarities of either a chemical or physical nature. It should be said at the outset, therefore, that in the present studies

no attempt has been made to include all types of bituminous coals, but only those of the Illinois field. In this series an effort has been made to cover a number of localities furnishing a fair representation of the different coals of the state. Briefly outlined the conditions under which the coals were studied were as follows. The starting point was the coal in its normal state, that is, as nearly as possible corresponding to the condition existing when broken out of the vein. The period of time between the mining of the coal and the initial analysis varied somewhat, but the first series of tests was made as soon as possible after the coal was mined. In the light of subsequent developments greater stress should be put on the early examination of samples to determine the initial condition. Even under the most careful disposition of samples in laboratory containers, a deterioration takes place which, while not exactly a "weathering" process, is still a large element in any study of the case and must be considered if exact conclusions are to be available. This feature will be more fully discussed under another heading[1].

There were nine initial samples taken of approximately 100 pounds respectively. The coal was of small lump or nut size and each sample was subdivided in order to subject the same kind of coal to various conditions. These conditions were to be continued through nine months and in general were:

(a) Outdoor exposure.

(b) Exposure to a dry atmosphere at a somewhat elevated temperature, ranging between 85° and 120° Fahr.

(c) Under the same conditions as (b) so far as temperature was concerned, but to be drenched with water two or three times per week.

(d) Submerged in ordinary water at a temperature approximately 70°.

The periods for examination were divided as nearly as the work would permit into

1. The initial analysis of the fresh coal.
2. After exposure for five months.
3. After exposure for seven months.
4. After exposure for nine months.

For the sake of comparison also the calorific values were determined under uniform conditions throughout by means of the Parr

[1]The Deterioration of Coal Samples.

calorimeter and the results calculated to the ash and water free basis to eliminate any variations in the process of sampling and to make as far as possible the different samples as well as the different lots comparable among themselves. The results for each sample are charted in the following diagrams, a discussion of which is taken up after the presentation of the charts.

Concerning these results as exhibited in the diagrams it should be noted that while experiments are of a preliminary nature largely devised to gain information for carrying out more elaborate and comprehensive tests, they are sufficiently consistent among themselves to justify certain tentative propositions as follows. There is evidence first of all of a distinct difference between the submerged coal and that which was exposed to the air. The values found for the submerged coal throughout the nine months did not vary, with possibly one or two exceptions, by greater amounts than would occur in tests made on succeeding days by the same operator. Values obtained so far apart as to time with the inevitable modifications due to temperature, atmospheric conditions, etc., may fairly be considered as checking if they agree within 100 or 150 units. There may indeed seem to be a uniform tendency to fall slightly in values, but from the showing the submerged coal may very fairly be said to remain constant. There may seem to be a slight inconsistency in this statement so far as chart No. 1 is concerned, there being a considerable drop in the value for the submerged coal. This may be the true state of the case, but more likely an explanation lies in the fact that initial values are too high. Some variables may have entered into the work at the outset that would not appear under the more settled conditions of routine and better control later on.

If we consider next the outdoor exposure, it should be said that these samples were contained in shallow boxes placed on the nearly flat roof of a building and subjected to the changes of temperature and moisture common to the months from October to July. The coals varied somewhat in their tendency to crumble, but all showed more or less of the "slaking" process. The remarkable fact in this series is the wide variation in the amount lost, ranging from approximately 2 to 10 per cent. The question naturally arises as to whether this is a natural characteristic of the different coals or whether the same variations would be found under different conditions, as for example, the storing in large

masses instead of the small lots worked with. Attention should also be called to the fact that during the progress of this work, as will be shown under another topic, proof was obtained of the positive loss of values in samples stored under supposedly the best laboratory conditions. The rate of progress of this loss has not been determined though it is presumably slow. The effort was made to obtain the initial values on all the samples to be subjected to weathering at the earliest possible date after being mined, but variations as to time were inevitable and the importance of guarding this point was not so fully appreciated at the outset as it was at the close of the work. In further studies along this line, this particular element in the case will be guarded with due care, but there is no evidence so far that the results would be materially affected or would be different from the general indication of the charts.

Not the least striking of all the results are those obtained from coal stored in a thoroughly dry atmosphere. The fact that these samples lost in the aggregate quite as seriously as those exposed to outdoor conditions, and, if anything, even to a greater extent, would seem to indicate that moisture has little to do with the processes of deterioration. It must be conceded, of course, that so far as relates to the weathering out of pyritic sulphur, moisture is an essential condition, but the losses are so much greater than would be represented by the leaching out of sulphur that this element is practically obliterated as a factor in the results. If anything is proved indeed concerning the effect of moisture, it is that it retards rather than accelerates the loss of heat.

Other facts than these just cited substantiate the above feature of the case, tending to show that, after all, weathering is not a leaching process, or one which primarily results from the direct action of water and attendant weather conditions, but seems to be a direct loss of volatile hydrocarbons. To how great an extent there is a reabsorption of atmospheric gases and to what extent oxidation accompanies such absorption can not be stated from this series of experiments. That water indirectly is a factor can not be doubted, for anything which promotes disintegration facilitates the escape of combustible gases. Disintegration results from handling, from freezing and thawing, and from the decomposition of pyrites. In general, we would expect

greater persistency of values in the dense and less friable coals, and in those with less of iron pyrites throughout their texture. In submerged coal, the decomposition of the pyrites is checked and without special reference to fineness of division. The loss of volatile matter seems also to cease. These processes which are active in the air and cease under water where the element of pressure or lack of it can hardly be a factor, suggest the idea of displacement of hydrocarbon gases by oxygen, by some process akin to osmosis or catalysis whereby a certain amount of oxidation of the carbon or hydrogen occurs. Altogether, the results are of value not only as touching the facts relating to the storage of coal, but especially as to their suggestions for further studies looking to fuller information of practical value on this very important topic.

Summary

(a) Submerged coal does not lose appreciably in heat value.

(b) Outdoor exposure results in a loss of heating value varying from 2 to 10 per cent.

(c) Dry storage has no advantage over storage in the open except with high sulphur coals, where the disintegrating effect of sulphur in the process of oxidation facilitates the escape of hydrocarbons or the oxidation of the same.

(d) In most cases the losses in storage appear to be practically complete at the end of five months. From the seventh to the ninth month, the loss is inappreciable.

(e) The results obtained in small samples are to be considered as an index of the changes affecting large masses in kind rather than in degree, but since the losses here shown are not beyond what seems to conform in a general way to the experience of users of coal from large storage heaps, it may not be without value as an indication of weathering effects in actual practice.

Further studies are to be continued, having reference to actual storage conditions.

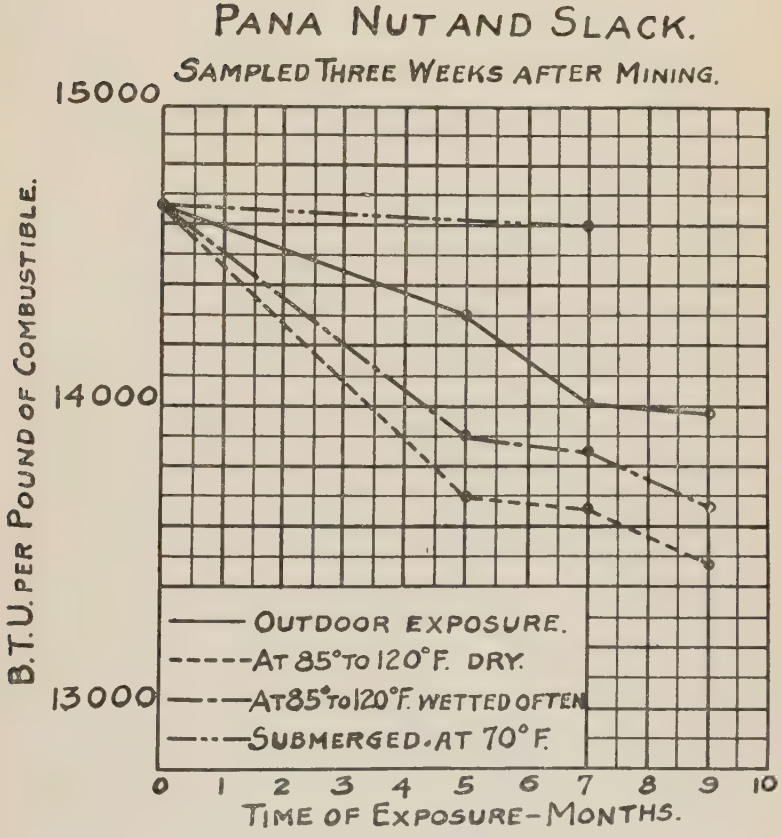
PANA NUT AND SLACK.
SAMPLED THREE WEEKS AFTER MINING.
15000
14000
13000
B.T.U. PER POUND OF COMBUSTIBLE.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE—MONTHS.

FIG. 1

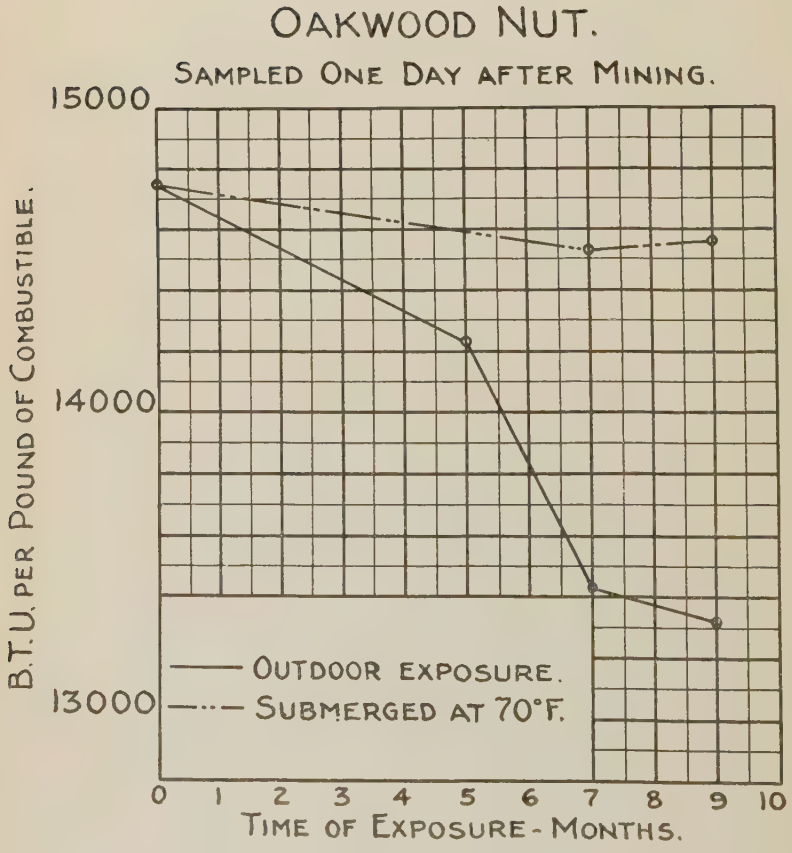
OAKWOOD NUT.
SAMPLED ONE DAY AFTER MINING.
15000
14000
13000
B.T.U. PER POUND OF COMBUSTIBLE.
OUTDOOR EXPOSURE.
SUBMERGED AT 70°F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 2

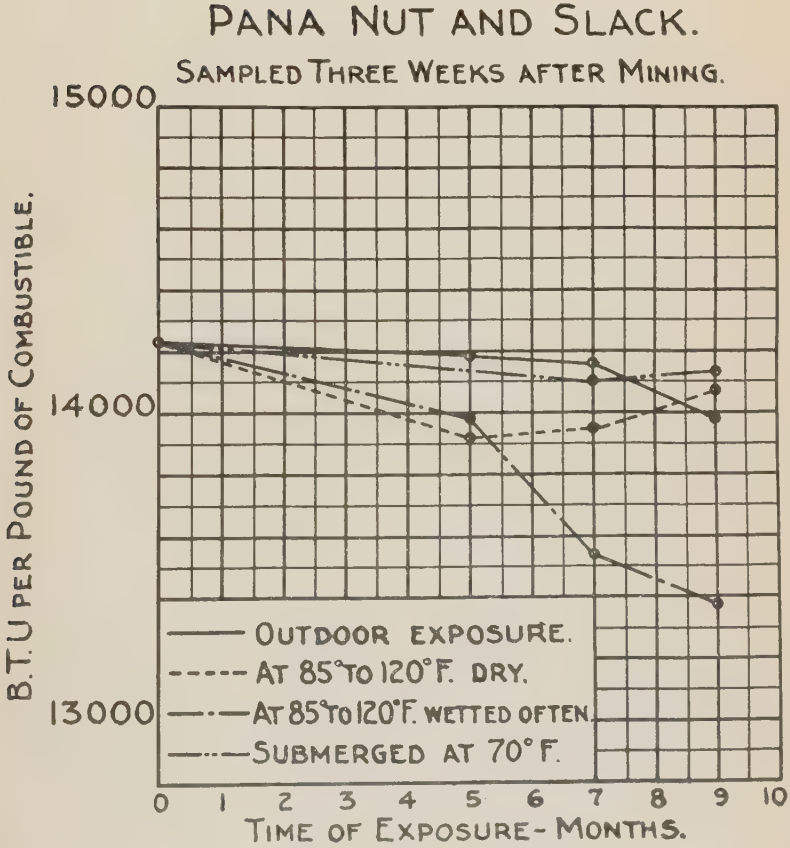
PANA NUT AND SLACK.
SAMPLED THREE WEEKS AFTER MINING.
15000
14000
13000
B.T.U PER POUND OF COMBUSTIBLE.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 3

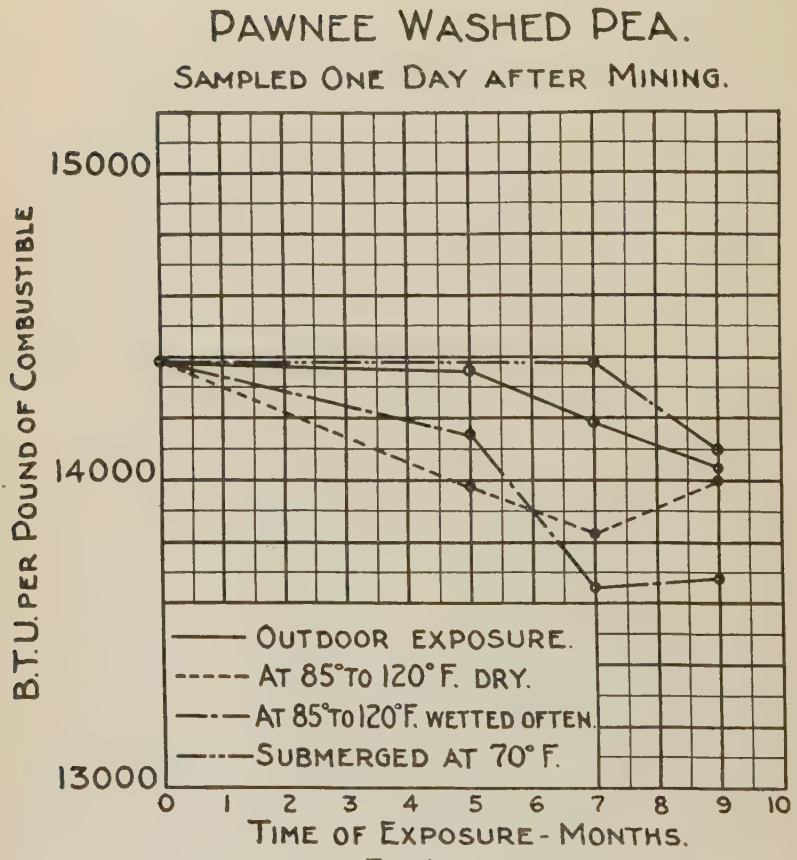
PAWNEE WASHED PEA.
SAMPLED ONE DAY AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.

FIG. 4

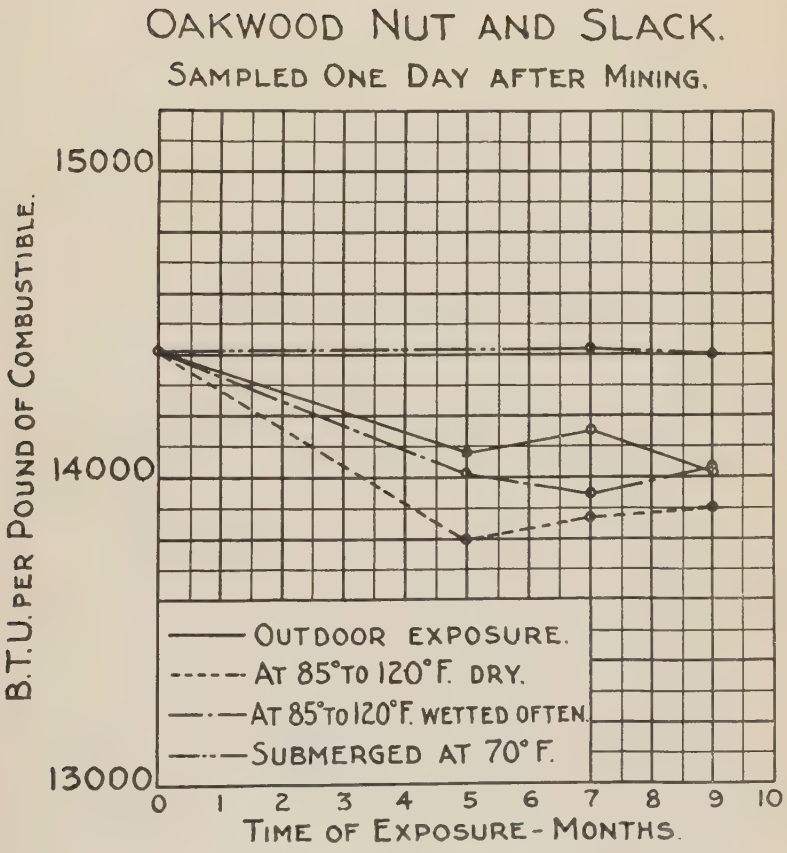
OAKWOOD NUT AND SLACK.
SAMPLED ONE DAY AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.

FIG.

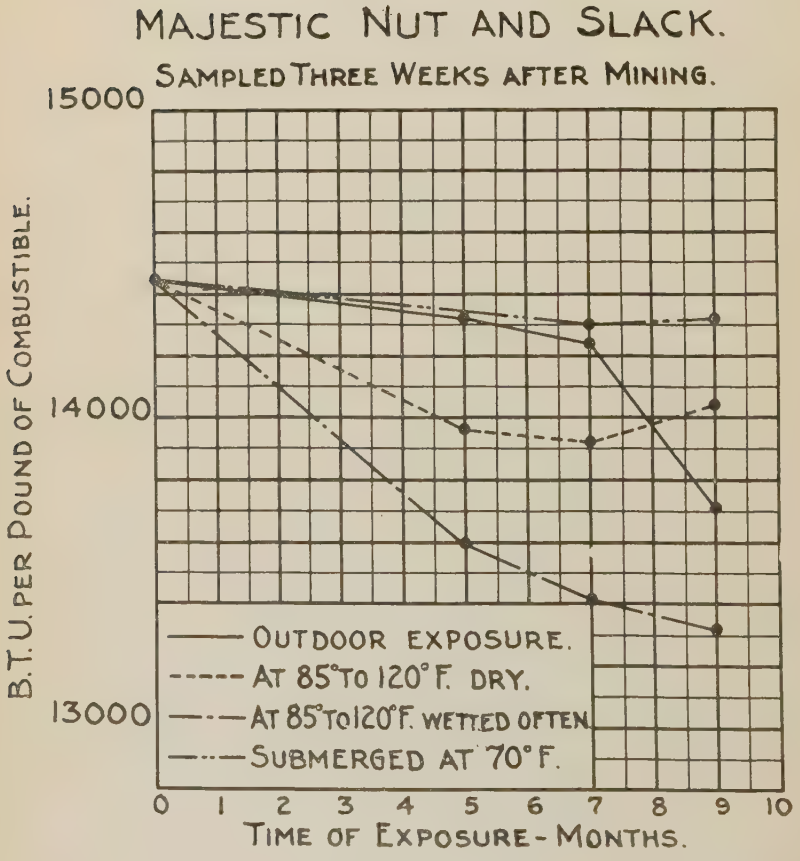
MAJESTIC NUT AND SLACK.
SAMPLED THREE WEEKS AFTER MINING.
15000
14000
13000
B.T.U. PER POUND OF COMBUSTIBLE.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 6

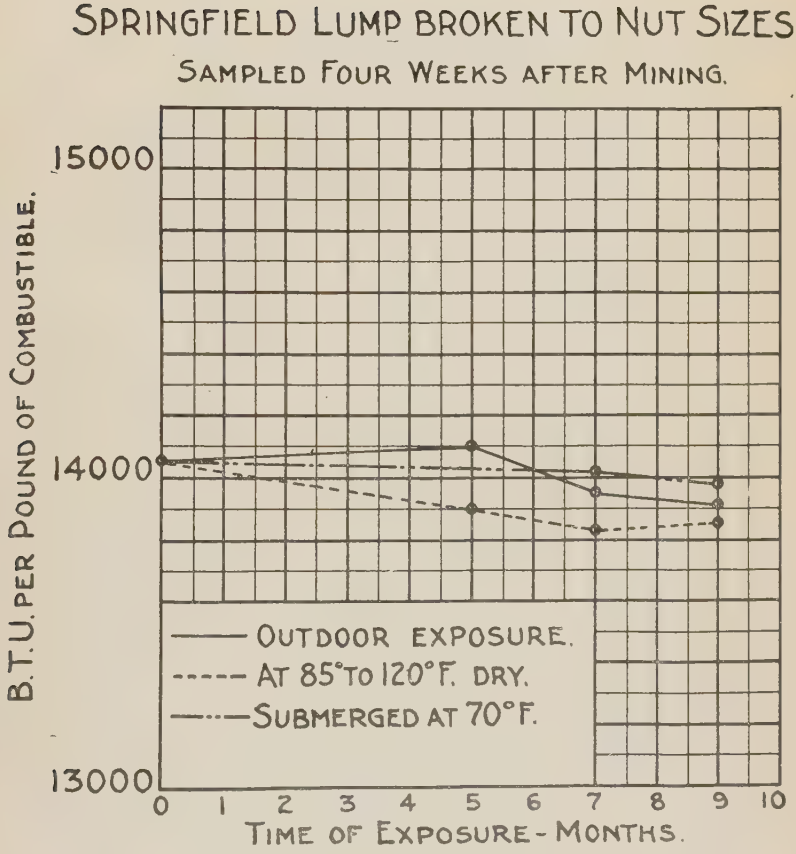
SPRINGFIELD LUMP BROKEN TO NUT SIZES
SAMPLED FOUR WEEKS AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
SUBMERGED AT 70° F.

FIG. 7

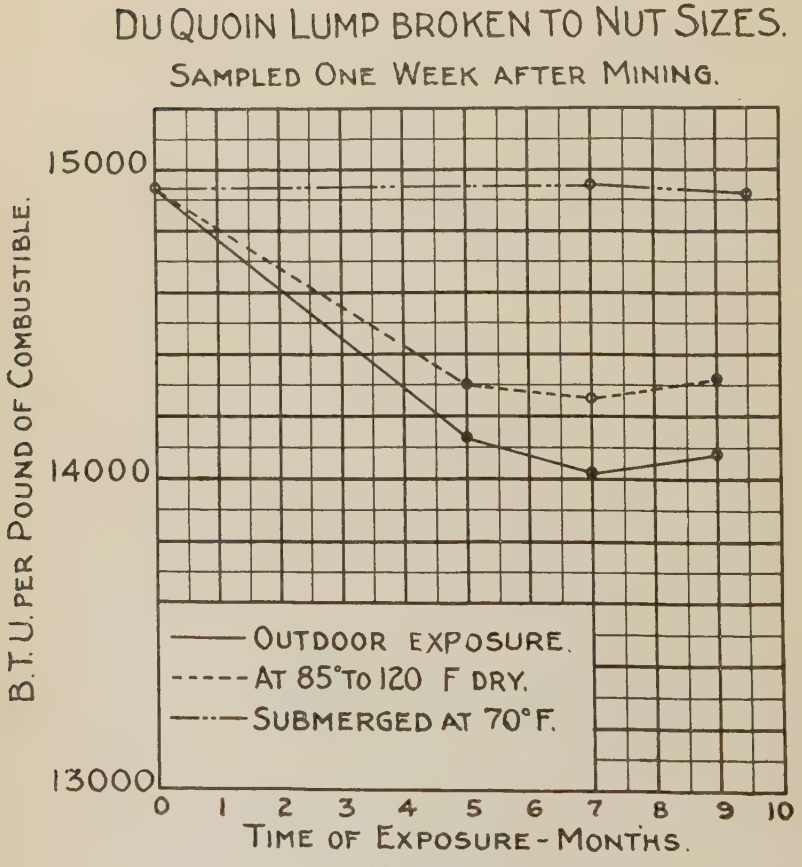
DU QUOIN LUMP BROKEN TO NUT SIZES.
SAMPLED ONE WEEK AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120 F DRY.
SUBMERGED AT 70° F.

FIG. 8

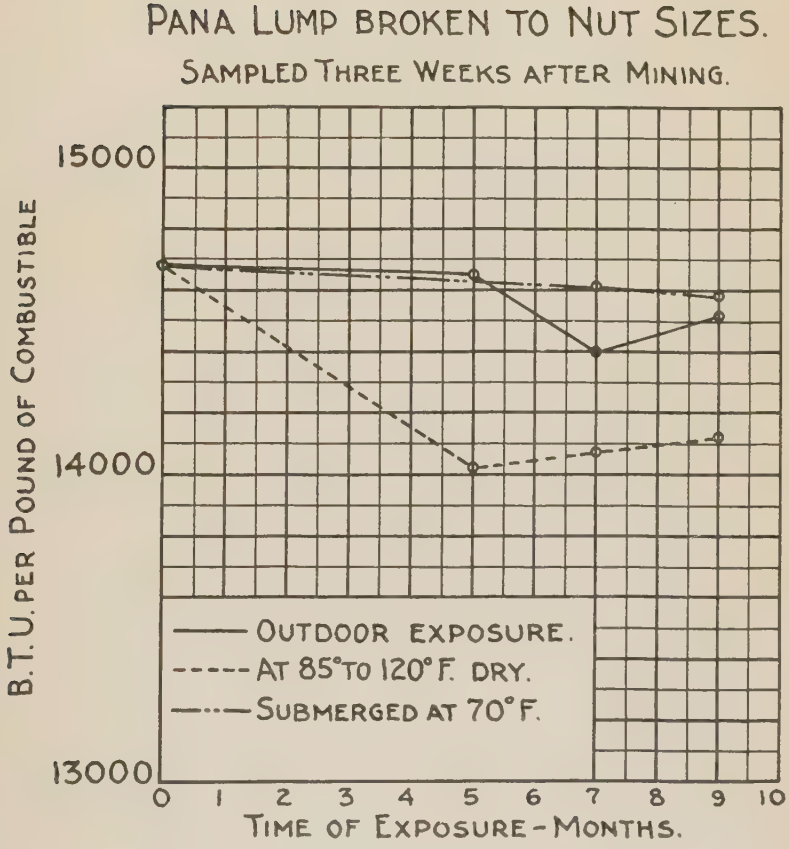
PANA LUMP BROKEN TO NUT SIZES.
SAMPLED THREE WEEKS AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
SUBMERGED AT 70° F.

FIG. 9

THE DETERIORATION OF COAL SAMPLES

By S. W. Parr, Professor of Applied Chemistry, and W. F. Wheeler, Assistant Chemist, Illinois State Geological Survey

(In Cooperation with the Illinois State Geological Survey)

Closely related to the weathering of coals is the subject of the deterioration of samples in storage. It would be assumed as a general proposition, that carefully sealed samples, kept at normal temperature, in glass containers, would remain constant as to their composition. Many facts have accumulated which seem to disprove this proposition. In an article by one of the writers[1], reference is made to the necessity of making calorific determinations where comparisons between different instruments are involved, at approximately the same date. To quote from that article —"A comparison of calorimeters should be made at approximately the same time. A series of calorific determinations made on finely ground samples on May 12, 1900, was found to give a reading 2.4 per cent less on July 12, 1900. It was necessary to repeat practically all of the above determinations on this account, all of the results showing a deterioration in the finely ground samples. This subject will receive further attention later."

In correspondence and conference with other workers, this fact has been questioned, as, for example, Dr. Bunte, of the Karlsrhue Polyteknikum, says that coal samples kept for analytical purposes, and which are determined by students year after year, give evidence of a constancy as to their calorific values. However this may be, the coals of the Mississippi Valley, being of a different type from the German coals, may not necessarily follow the same behavior in storage. Indeed, it may be doubted if the coals of Western Pennsylvania and Virginia would show the same behavior in this respect as the coals of the Mississippi Valley.

[1] A New Coal Calorimeter, by S. W. Parr, Jour. Am. Chem. Soc., Oct., 1900, p. 650.

At any rate, there have accumulated a number of facts which point to the deterioration of Illinois coal samples in laboratory storage and it is the purpose of this paper to give the evidence which has come to hand up to the present time.

The matter is of importance, not only from its bearing upon an understanding of the matter of the weathering of coals, but in connection with all matters pertaining to the comparison of values as between different samples. It is to be taken into account also in considering the value which is to be placed upon the "pure coal" idea as frequently set forth, to the effect that the ash and water free basis is common ground for comparison under all conditions. It is exceedingly helpful and indeed essential, in the scientific study of coals, to have a unit of reference which may be used as a basis of comparison, but it is essential also to know the variations which may enter into such a unit, in order to avoid errors in the ultimate conclusions.

In comparing the values of Illinois coals, as obtained by the United States fuel testing plant at St. Louis, with the values determined in this laboratory by the Illinois State Geological Survey on coals from the same districts, it was found that considerable discrepancy existed upon referring the results in both cases to unit basis, as, for example, the ash and water free condition. Perhaps the most striking fact in this connection was the uniformly lower calorific values obtained by the State Geological Survey. The possibility of this difference being due to variations in methods and to different operators was duly considered. However, the method of sampling at the mine was the same, the sample being taken from the face of the vein, reduced by quartering in the usual manner to about two pounds in weight, sealed in tins with screw cap and insulating tape, exactly as followed by the fuel testing plant at St. Louis[1]. The type of calorimeter was also duplicated, the instrument in this laboratory used in this comparison, being of the Mahler-Atwater type with platinum lining and operated in a room under temperature control. A careful standardization of the instrument and a redetermination of its water equivalent were also made. The results here were so uniformly lower than those obtained at St. Louis as to call for a special study to ascertain the cause. An examination of the accom-

[1]U. S. Geol. Surv. Coal Testing Plant, Bul. 261, p. 20.

panying table will make evident the difference in calorific values as above described.

It is not a sufficient explanation to say that the samples in the two cases were not identical. Indeed, frequently they were not taken from the same mine. It is a well established fact, however, that samples taken from the same locality, when referred to a unit basis, as the ash and water free conditions, will show relatively small variations, at least, within a limited area. It is true that variations in the same region do occur often, but evidence of these variations is largely dependent upon the accuracy of the unit adopted for reference, and when properly compared, these variations are not of sufficient size nor of sufficient uniformity to explain either the magnitude or the constancy in direction of the differences shown in the accompanying table. Concerning the unit of reference, it should be said that the ash, moisture and pyrite-free basis is used as approaching the nearest possible to the actual material under consideration, thereby eliminating such variables as would obviously result if no notice were taken of the presence or absence of sulphur. The weight of ash, therefore, is corrected by adding $\frac{5}{8}$ of the weight of sulphur present, as representing the original pyritic condition.

In taking up the study of the conditions under which the work was carried on in the two laboratories, so far as can be determined, the only point of divergence seemed to reside in the time elapsing between the date of sampling at the mine and the date at which the determinations were made in the laboratory. In the case of the fuel testing plant at St. Louis, this difference in time was relatively short, being presumably, as a rule, not more than two or three weeks. In the case of the State Geological Survey, because of certain exigencies, an unavoidable delay occurred, hence the time elapsing varied from six months to a year.

Two methods of caring for the samples were followed. First, where time permitted, the coal as received in the tins was at once emptied into shallow pans and the amount of moisture lost upon air drying was determined by allowing the pans to stand exposed to the air over night. The sample was then reduced to buckwheat size, one-half was sealed in glass jars, of the so called Lightning or Putnam pattern, and the other half was ground in the Ball mill with porcelain jars of the Abbe type. This part of the sample was also sealed in a similar jar and set aside for the

analytical work later. The analyses used in Table 1 for comparison with the St. Louis results were made on these finely ground portions.

The other method of caring for the samples consisted in simply transferring the coal as received in the tins to glass containers without air drying. Fifty samples were thus disposed of, about half being stored in the Putnam jars and half in jars of the common Mason type.

TABLE 1

COMPARISON OF NEW AND OLD SAMPLES OF ILLINOIS COALS

In Laboratory Storage

Sample Numbers	Locality	Mine Sample U. S. G. S. Ash, Moisture and Pyrite Free	Mine Sample Ill. Geol. Surv. Ash, Moisture and Pyrite Free	Difference	Per cent of Variation
U. S. G. S., Ill. No. 1 Ill. Geol. Surv. No. 95	O'Fallon O'Fallon *a*	14567	14084	483	-3.31
U. S. G. S., Ill. No. 3 Ill. Geol. Surv. No. 330	Marion Marion *a*	14561	14335	226	-1.55
U. S. G. S., Ill. No. 9 Ill. Geol. Surv. No. 94	Staunton Staunton *a*	14615	13923	692	-4.72
U. S. G. S., Ill. No. 10 Ill. Geol. Surv. No. 364	W. Frankfort W. Frankfort *b*	14647	14332	315	-2.15
U. S. G. S., Ill. No. 11 Ill. Geol. Surv. No. 325	Carterville Carterville *a*	14731	14213	518	-2.15
U. S. G. S., Ill. No. 15 Ill. Geol. Surv. No. 167 Ill. Geol. Surv. No. 169	Centralia Centralia *b* Centralia *a*	14587	 14200 14376	 387 211	 -2.65 -1.44
U. S. G. S., Ill. No. 16 Ill. Geol. Surv. No. 323	Herron Herron *a*	14558	14321	237	-1.62
U. S. G. S., Ill. No. 18 Ill. Geol. Surv. No. 393	LaSalle LaSalle *b*	14440	14722	282	-1.91

(a) not same mine
(b) same mine

As already noted, it has been impossible in this table of comparisons to select cases where the samples were exact duplicates

from the same mine in each instance, but it may fairly be claimed that the uniformity with which the lower values are indicated for the older samples precludes the possibility of ascribing the difference to the character of the coal. The same thing may also be said with reference to variations in results which may be expected from different operators. If this were the reason for the discrepancy, one would hardly expect the uniformity as to direction of the results here indicated in the tables. To determine whether deterioration might result from the finely ground state of the samples, the reserve sample in the coarse condition in a number of cases was taken and calorific determinations made as upon the fine samples. These results were found practically to duplicate those obtained upon the ground samples. Hence, it was concluded that if deterioration were the explanation, it had affected both the coarse and fine samples alike. It was then decided to obtain new samples from the same localities and so far as possible from the same mines, collecting and preparing the samples in exactly the same way as before. The determinations on these samples were made within a period not to exceed ten days from the date of collection. The results arranged for comparison with the old samples are shown in Table 2. The striking uniformity with Table 1 is to be noted in that practically the same difference in values is shown between the new samples and the old as exists between the St. Louis results, presumably, also on fresh samples, and our own results known to be on samples of from six months' to a year's standing.

TABLE 2

COMPARISON OF COAL SAMPLES FOR VARYING LENGTHS OF TIME IN LABORATORY STORAGE

Lab. No. Ill. State Geol. Survey	Source of Sample	Time of Storage	B. t. u. of Ash, Moisture and Pyrite free	Loss in B. t. u.	Percentage of Loss
421	Majestic Mine, DuQuoin, Ill. Apr. 17, 1907	10 days	14386		
307	Paradise Coal & Coke Co., DuQuoin, Ill.	1 year	14116	207	–1.9

TABLE 2 (*Continued*)

Lab. No. Ill. State Geol. Survey	Source of sample	Time of storage	B. t. u. of Ash, Moisture and Pyrite free	Loss in B. t. u.	Percentage of Loss
459	Big Muddy C. & I. No. 7 Apr. 18, 1907	10 days	14615		
323	Squirrel Ridge Mine Herrin, Ill.	1 year	14321	294	-2.0
460	Big Muddy Coal Co. No. 8, Clifford, Apr. 18, 1907	10 days	14615		
325	Clifford, Carterville	1 year	14213	402	-2.7
462	Peabody Coal Mine No. 3 three miles west of Marion, Ill. Apr. 18, 1907	10 days	14781		
330	Peabody Coal Co., Marion, Ill.	1 year	14335	446	-2.6
540	Sangamon Mine, Springfield	1 week	14567		
82	Sangamon Mine, Springfield	7 months	14100	467	-3.2
81	Sangamon Mine, Springfield	7 months	13940	841	-4.3
557	Kelly No. 4, now Dearing No. 44	5 days	14450		
332	Kelly Coal Co., Westfield, Ill.	1 year	14054	396	-2.8
558	Kelly Coal Co., Himrod Mine, Himrod, Ill.	5 days	14564		
333	Himrod Mine, Himrod, Ill.	1 year	14087	477	-3.3

Still a third series of results has been arranged in Table 3. Here the comparison is made between the St. Louis values and our own, obtained on relatively fresh samples from the same or near-by mines. There is further confirmation of the proposition here in that the results on our own samples are sometimes higher and sometimes lower than the St. Louis values. The relative dates are not at hand in each case to indicate whether or not the plus and minus values conform to a greater or less transpiration of time before analysis but it is worthy of noting that the discrepancies are not so wide as in Tables 1 and 2, where a positive and wide variation of time existed. Even in the third sample from Stanton (Table 3) where a difference of 2.14 per cent is indicated, in Table 1 for the same mine, a difference of 4.72 per cent is given.

TABLE 3

COMPARISON OF ILLINOIS COAL SAMPLES WITH RELATIVELY SHORT PERIOD IN LABORATORY STORAGE

Sample Numbers	Locality	Mine Sample U. S. G. S. Ash, Moisture and Pyrite Free	Mine Sample Ill. Geol. Surv. Ash, Moisture, and Pyrite Free	Difference	Per cent of Variation
U. S. G. S. Ill. No. 3	Marion	14561			
Ill. Geol. Surv. No. 462	Marion *a*		14781	220	+ 1.51
U. S. G. S. Ill. No. 7	Collinsville	14373			
Ill. Geol. Surv. No. 725	Collinsville *b*		14659	286	+ 1.98
Ill. Geol. Surv. No. 723	Collinsville *a*		14640	267	+ 1.8ε
Ill. Geol. Surv. No. 724	Collinsville *a*		14564	191	+ 1.32
U. S. G. S. Ill. No. 9	Stanton	14615			
Ill. Geol. Surv. No. 737	Stanton *a*		14301	314	− 2.14
U. S. G. S. Ill. No. 11	Carterville	14731			
Ill. Geol. Surv. No. 460	Carterville *b*		14615	116	− .787
U. S. G. S. Ill. No. 14	E. Springfield	14464			
Ill. Geol. Surv. No. 540	E. Springfield *a*		14567	103	+ .711
Ill. Geol. Surv. No. 740	E. Springfield *a*		14408	56	− .387
Ill. Geol. Surv. No. 741	E. Springfield *a*		14429	35	− .243

TABLE 3 (*Continued.*)

Sample Numbers	Locality	Mine Sample U. S. G. S. Ash, Moisture and Pyrite Free	Mine Sample Ill. Geol. Surv. Ash, Moisture and Pyrite Free	Difference	Per cent of Variation
U. S. G. S. Ill. No. 16 Ill. Geol. Surv. No. 459	Herron Herron *b*	14558	 14615	 57	 + .391
U. S. G. S. Ill. No. 19 Ill. Geol. Surv. No. 419 Ill. Geol. Surv. No. 420	Ziegler Ziegler *b* Ziegler *b*	14601	 14480 14445	 121 156	 − .829 −1.06

(*a*) Not same mine.
(*b*) Same mine.

It is now in order to refer to certain other facts which still further confirm the proposition in hand. The fifty samples above referred to (p. 29) as having been transferred without air drying to glass containers upon their arrival at the laboratory, were examined after about ten months' standing. Twenty-nine of the samples had been placed in the type of jar shown herewith and known as the Lightning or Putnam jar. Extended experience with this jar as a container for sodium peroxide, a chemical with unusual avidity for moisture from the atmosphere, has proved it to be possessed of an absolute seal. The remaining twenty-one samples had been placed in the common Mason fruit jar with metal screw cap and very indifferent seal. After the ten months of storage, upon opening the Lightning jars a slight pressure of gas was noted which suggested the testing of the same with a lighted match. In twenty-six of these jars the gas ignited with a strong blue flame, burning up from one-half to six inches above the top of the jar. Upon covering with the cap and testing again with a match, these jars would reignite for two or three successive times. Two of the jars had been previously opened without attention to the contents and it is not known whether they contained inflammable gas or not. In one other of these jars, the gas was carbon dioxide, judging from the fact that instead of igniting the match was extinguished. Not one of the Mason jars with the zinc cover contained any pressure of gas and no tendency to ignite was manifested. It should be noted that all of these jars were

in diffused light, but not in direct sunlight, and that only the Lightning jars possessed perfect seal. By reference to Fig. 10, it

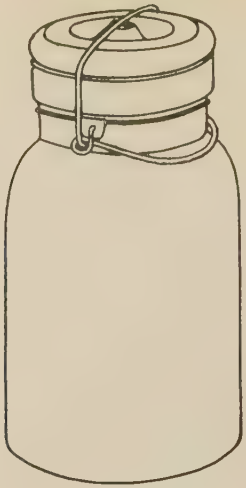

FIG. 10

will be seen that, with the exception of the rubber gasket, the entire inclosure of the material is of glass. The gasket, however, is an exception to this, but it is held with a very positive pressure by reason of the lever device for clamping on the top. The conditions in the ordinary Mason jar are different in that a metal screw cap is employed and the positiveness of the seal of the rubber gasket is questionable. We have herein evidence of the tendency of the coal to give off combustible gas after being broken out of the vein, and if we accept the theory proposed by Richter and others, that this exudation of combustible gas is accompanied by a corresponding absorption of oxygen from the air, we may readily understand some of the processes which go on in the deterioration of samples as well as in the weathering of coal.

One further incident is worthy of notice in this connection. Certain samples used in Coal Bulletin 2, published as the University of Illinois Studies on the Composition of Coal, 1904, were opened after three years of storage in jars of the Lightning type as above described. These samples had not been opened during the three years. It was noted that much of the iron pyrites disseminated throughout the coal had become oxidized to ferric sulphate. This suggested that by leaching out this com-

pound, and estimating the sulphur thus transformed to sulphate, we could calculate the amount of oxygen necessary to bring about the reaction from the form of iron pyrites, (FeS_2) to ferric sulphate, $Fe_2(SO_4)_3$. It was found that the amount of oxygen required to oxidize the weight of sulphur found was 1.99 grams and calculated to the equivalent volume of pure oxygen would be 1.39 liters, or, if calculated to the equivalent of atmospheric air, it would require 7 liters of such air to furnish the necessary oxygen for the reaction. When it is remembered that the jars in which these samples were kept had a volume all told of only one pint and that this space was occupied at least to the extent of three quarters of the total with coal of buckwheat size; and when we further remember that these jars were possessed of absolute seal, without opportunity for transference of oxygen from without, there is furnished evidence of the fact that occluded oxygen or absorbed air must have been present in sufficient amount to accomplish the work indicated by the transformation of the pyrites to ferric sulphate.

It would seem from the above experiences that there is not only sufficient evidence to establish the fact of the deterioration of coal samples but a fairly well established explanation as to how this deterioration takes place. Other tests along this same line are being carried out from still other standpoints, and while they are not complete, the evidence is all in the same direction as that adduced above.

Summary

(a) An exudation of combustible gases from coal occurs from the time of breaking out of the sample from the vein.

(b) An absorption of oxygen accompanies the exudation of hydrocarbons.

(c) Samples of coal in most carefully sealed containers are subject to deterioration.

(d) The process of deterioration is probably due to oxidation of hydrogen or hydrocarbons by means of the absorbed oxygen. It may also be due to a simple loss of combustible gases and the replacement of the same by non-combustible gases such as oxygen.

(e) The rapidity or extent of this deterioration varies with different coals but is probably most active during the first two or three weeks from the taking of the sample, but does not seem to

reach a normal state till after a few months have elapsed. Further data on this point especially are necessary.

It is interesting, also, to bring together the averages of the results in the three tables for further comparison. There is thus afforded further evidence suggesting the fact of deterioration.

TABLE 4

Averages from Tables 1, 2 and 3

Illinois State Geological Survey Eight old in comparison with eight new samples— from Table 1.	Average 2.85 per cent lower
Illinois State Geological Survey Nine old samples in comparison with nine results by U. S. G. S.— from Table 2.	Average 2.40 per cent lower
Illinois State Geological Survey Twelve fresh samples in comparison with results by U. S. G. S.— from Table 3.	Average 0.20 per cent higher

PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N Talbot. 1904. (*Out of print*).

Circular No. 1. High Speed Tool Steels, by L. P. Breckenridge. 1905.

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905.

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906.

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. (*Out of print*).

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906.

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman. 1906. (*Out of print*).

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906.

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr and Henry B. Dirks. 1906.

Bulletin No. 8. Tests of Concrete: I. Shear; II. Bond, by Arthur N. Talbot. 1906. (*Out of print*).

Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906.

Bulletin No. 10. Tests of Plain and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907.

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907.

Bulletin No. 12. Tests of Reinforced Concrete T-Beams, Series of 1906, by Arthur N. Talbot. 1907.

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907.

Bulletin No. 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot. 1907.

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1907.

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1907.

Bulletin No. 17. The Weathering of Coal, by S. W. Parr and N. D. Hamilton. 1907.

Bulletin No. 18. Stresses in Chain Links, by G. A. Goodenough. 1907. (*In press*).

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon and Tantalum Filament Lamps, by Thomas H. Amrine. 1907.